Extreme Energy Cosmic Rays (EECR) Observation Capabilities of an "Airwatch from Space" Mission

presented by C. N. De Marzo[a] for the Airwatch Collaboration[(*)]

[a]Dipartimento di Fisica, Università e Sezione INFN, Bari, Italy, e-mail: demarzo@ba.infn.it

The longitudinal development and other characteristics of the EECR induced atmospheric showers can be studied from space by detecting the fluorescence light induced in the atmospheric nitrogen. According to the Airwatch concept a single fast detector can be used for measuring both intensity and time development of the streak of fluorescence light produced by the atmospheric shower induced by an EECR. In the present communication the detection capabilities for the EECR observation from space are discussed.

1. The Airwatch from space mission

EECR with energies $> 10^{20}$ eV have been detected through the giant showers they produce in the atmosphere [1]. Their existence raises questions on their origin and propagation mechanism above the 'Greisen-Zatsepin-Kuzmin' cutoff [2] in the energy spectrum at $\sim 6 \times 10^{19}$ eV. Because of their very high energy, if EECR point to definite sources, an explanation in terms of a "bottom-up" acceleration mechanism would be favoured. On the other hand, if they indicate broader or structured regions, a "top-down" model considering them as decay products of topological defects should be taken into account [3]. The EECR shower development is accompanied by UV emission, in particular by the fluorescence light induced in the atmospheric nitrogen which has characteristic spectral lines in the near UV. The possibility to detect air showers through the fluorescence light they produce has been proven by detectors like Fly's Eye [4], whose operation has given information on flux, incoming direction and composition of the primary particles.

An atmospheric mass 2-3 orders of magnitude larger can be monitored by detecting the fluorescence light induced by EECR in the atmosphere from a space platform [5]. The proposed "Airwatch" Mission appears to have the capability of measuring the EECR spectrum above 10^{20} eV, by determining the arrival direction, the energy, the X_{max} and the primary species for each shower. This capability appears to provide a complemental approach to large ground arrays and promises the possibility of extending EECR measurements beyond 10^{21} eV [6,7].

The amount of atmospheric area and mass that can be observed from a space platform with reasonable design parameters — orbit height and field of view (FOV) — is given in Tab. 1. It should be considered that the atmospheric mass observed by Flye's Eye is of the order of 10^9 tons.

The fluorescence light produced by an atmospheric shower of extreme energy is mainly emitted in the near UV molecular nitrogen lines 337, 357 and 391 nm. As seen from space, in these spectral bands the shower appears as a spot of light travelling with speed near to that of light and with changing intensity. The fluorescence light is accompanied by Cherenkov light, by Rayleigh and Mie scattered Cherenkov light. All these components may be reflected on clouds or ocean surface ('end point flash'). These optical phenomena bring further information on the shower development. The spot velocity, projected on the horizontal plane, equals the velocity of light times the cosine of the angle of its direction with the horizontal plane. This fact provides one possible approach to measure the direction of the shower axis: i.e. by measuring the velocity position and time of the pixels fired in the focal plane detector.

In an alternative approach 2 focal plane detectors on 2 separate platforms, orbiting 600 km apart, are used for stereoscopic view - OWL con-

Table 1
Atmospheric area and mass as a function of orbit height and FOV.

Orbit height (km)	FOV (degrees)		
	60^{O}	90^{O}	120^{O}
400	0.17×10^6 km^2	0.50×10^6 km^2	1.5×10^6 km^2
	1.7×10^{12} ton	5×10^{12} ton	15×10^{12} ton
500	0.26×10^6 km^2	0.80×10^6 km^2	2.4×10^6 km^2
	2.6×10^{12} ton	8×10^{12} ton	24×10^{12} ton
600	0.38×10^6 km^2	1.1×10^6 km^2	3.4×10^6 km^2
	38×10^{12} ton	11×10^{12} ton	34×10^{12} ton

cept [7].

Assuming that the shower streak of light is long 10 to 100 km in the atmosphere, the Airwatch focal plane detector segmentation must be of the order of 1000×1000 pixels for monitoring one million km^2 of atmosphere with sufficient resolution and counts per year. Assuming a 5 m^2 light collector (1.3 m radius) and resonable values for its optical efficiency; considering that fluorescence light yield, in the 300–400 nm spectral interval, is ~ 4 *photon*/(*particle*$\cdot$ m) and that a 10^{20} eV shower has 6×10^{10} particles at its maximum development, the detector sensitivity has to work at a level of 10–100 *photons*/*pixel* on integration times of about 3 μs. These requirements ask for a detector technology based on photon-electron conversion on a photocathode and subsequent electron multiplication.

The effective counting rate for an Airwatch Mission depends on the amount of watched atmosphere and on the shape of the energy spectrum. On the higher energy side counting rate is limited by the EECR low flux. On the lower energy side the detection efficiency depends on the trigger sensitivity. The trigger electronics of an Airwatch from Space Mission can take advantage of the unique features of the showers: there is no possible background looking like a luminous spot moving at light speed through the atmosphere over tens of kilometers. The Airwatch detector and its trigger need to be smart in detecting showers on the lower energy side. At present stage of the project an energy threshold something below 10^{20} eV appears reachable, allowing the comparison with measurements of ground based detectors and arrays. For an atmospheric mass $\sim 10^{12}$ tons, an order of 100 events per year could be collected above 10^{20} eV.

Operations with a $10 \div 20\%$ duty cycle are predicted for an Airwatch Space Mission, taking into account sunlight, moonlight, civilization ground lights, high clouds and average weather patterns. An equatorial orbit will maximize observation time over oceans and deserted areas. Radiation degradation of the optics is also minimized. Conversely, one drawback of an equatorial orbit is the higher cloud coverage.

To pursue a complete study of all the sources of background — meteors, aurorae, lightining — foreseen for the experiment, a precursor measurement of the light phenomena in the atmosphere (EAGLE Mission) has been proposed [8].

2. On neutrino and GRB detection

In a "top-down" acceleration scenario, a sensible flux of ν's is expected on the Earth up to EECR energies. Airwatch from Space can detect them because of the huge and transparent target ($\sim 10^{12}$ tons) available for interaction and detection. Moreover, it has been shown that the cross section for ν interaction will increase with energy up to the order of 10^2 nb at 10^{20} eV [9]. Because atmospheric thickness rises of about a factor 40 as shower direction goes from vertical to horizontal angle, EECR showers initiated by neutrinos can be identified by their appearance at large zenith angles and large atmospheric depths where no hadron or photon initiated showers can be present.

While EECR showering in the atmosphere will appear as UV tracks spatially well defined and

short in time, a GRB will arrive as a plane wave investing the entire atmosphere and exciting by Compton electrons a diffuse fluorescence emission having a peculiar space-time function [10]. This signal can be detected by Airwatch and possible correlations between EECR and GRB's can be studied.

3. Discussion and prospects

The main design parameter for an Airwatch experiment is the height of the orbit. At fixed FOV, on one hand the monitored atmospheric mass increases with the orbit altitude; on the other hand the signal strength decreases. The optimum solution must be decided through an effective simulation of the detector performance.

A possible approach could be based on the segmentation of the mission in a certain number of small satellites. This scenario would in general be cheaper and have a faster schedule than the traditional single or double observatory, presenting the possibility to be implemented with the methodology used in manufacturing large number of telecommunication satellites.

This solution can be approached through an exploratory mission on a single small satellite that will be very useful both from the engineering and the physical point of view. A spacecraft in the range of 400 kg and 400 W can have a collection capability of some tens of events per year, still providing very interesting results for the EECR study. Finally, the possibility to locate an Airwatch from Space Mission on the Space Station would offer several technical advantages, not least the opportunity to use a 9 m diameter collecting mirror whose technology is available [11].

REFERENCES

1. D. J. Bird *et al.*, Ap.J. **424** (1994) 491; S. Yoshida *et al.*, Astrop. Phys. **3** (1995) 151.
2. K. Greisen, Phys. Rev. Lett. **16** (1966) 748; G. T. Zatsepin and V.A.Kuzmin, JEPT Lett. **4** (1966) 78.
3. G. Sigl *et al.*, Science **270** (1995) 1977.
4. R. M. Baltrusaitis *et al.*, Nucl. Instr. & Meth. **A240** (1985) 410.
5. J. Linsley, USA Astronomy Survey Committee Documents (1979); MASS/AIRWATCH Huntsville Workshop Report (1995) 34.
6. Y. Takahashi, Proc. 24^{th} ICRC, Rome, Italy, **3** (1995) 595.
7. L. M. Barbier *et al.*, Proposal subm. to NASA (1996); J. Ormes *et al.*, Proc. 25^{th} ICRC, Durban, South Africa, **5** (1997) 273.
8. C. N. De Marzo *et al.*, Proposal subm. to ESA (1997).
9. R. Gandhi *et al.*, Astrop. Phys. **5** (1996) 81.
10. O. Catalano *et al.*, Proc. 25^{th} ICRC, Durban, South Africa, **7** (1997) 365.
11. G. K. Garipov *et al.*, *Project "Klypve"* private communication.

(*) **The Airwatch Collaboration:**

M. Ambriola, R.Bellotti, F. Cafagna, F. Ciacio, M. Circella, C.N. De Marzo, N. Mirizzi, T. Montaruli - *Fisica, Università e Sezione INFN, Bari, Italy.*

G. Giovannelli, I. Kostandinov - *FISBAT-CNR, Bologna, Italy.*

G. Bonanno - *Oss. Astrofisico, Catania, Italy*, R. Fonte - *Sezione INFN, Catania, Italy and Univ. of New Mexico, Albuquerque, USA.*

O. Adriani, G. Becattini, P. Spillantini - *Fisica, Università di Firenze, Italy.*

P. Mazzinghi, G. Toci - *IEQ-CNR, Firenze, Italy.*

F. Fontanelli, V. Gracco, A Petrolini, G. Piana, M. Sannino - *Fisica, Università e Sezione INFN, Genova, Italy.*

G. D'Alì, L. Scarsi - *Energ. ed Appl. Fisica, Università di Palermo, Italy.*

G. Agnetta, O. Catalano, S. Giarrusso, M.C. Maccarrone, B. Sacco - *IFCAI-CNR, Palermo, Italy.*

P. Lipari - *Sezione INFN, Roma, Italy.*

M. Stefani - *Fisica, Università di Roma 3, Italy.*

G. Giannini - *Fisica, Università di Trieste, Italy.*

V. Bratina, A. Gregorio, R. Stalio, P. Trampus, B. Visintini - *CARSO, Trieste, Italy.*

C. Cepek, A. Laine, E. Mangano, M. Sancrotti - *Laboratorio TASC-INFM, Trieste, Italy.*

J.N. Capdevielle - *L.P.C. Collége de France, Paris.*

B. Khrenov, M. Panasyuk - *Skobelisyn Institute of Nuclear Physics, Moscow State University, Russia.*

J. Linsley - *Univ. of New Mexico, Albuquerque, USA.*

Y. Takahashi - *Univ. of Alabama, Huntsville, USA.*

L.A. Broadfoot - *Lunar and Planetary Lab., Univ. of Arizona, Tucson, USA.*